THE THAMES AND ITS EMBANKMENTS;

WITH REMARKS ON THE MOTION AND ACTION OF RUNNING WATER.*

BY JOHN PHILLIPS.

The action of running streams upon their channels depends upon the declivities, and the nature of the soil; but the action of the augmented velocity at the parts to be embanked will ultimately produce an increased depth of the channel, as the scour will continue to act with greater mechanical effect, more particularly upon the bottom of the channel in the middle of the run of the stream, until the resistance offered by the hardness and tenacity of the soil, and also the diminished declivity, becomes somewhat equal to the velocity and the abrading action of the water. It is impossible that the resistance of any material, mathematically considered, can ever be equal to the power exercised by the abrasion of the water; but in order to produce and retain an uniform channel, and by these means a regimen to the stream, other causes, both natural and artificial, have generally an influence, and are brought to aid this purpose. The momentum of the velocity of the *river-water*, assisted by the inclination of the bed, have considerable influence in checking and retarding, during the first quarter, the flow of the tide, as far as the action of the latter reaches; and the resistances offered by either are as the squares of their reciprocal velocities; so that whichever has the greatest momentum (the flowing tide against the reaction of the river-water, and *vice versâ*), the other must give way to it as a matter of course; but as soon as the action of the flood from the momentum of the sea overcomes the partial resistance of the river-water, the velocity and power of the former will begin to augment accordingly. In many parts of a tidal river these conflicting actions of the streams have considerable tendencies towards producing shoals and bars across the channel. Where the downward stream meets the flood, the ripple and regurgitation of the contending waters disturb the loose sand and gravel of the bed, which being suspended, are carried away with the set of the revolving waters, and thus become deposited as shoals and bars in the eddies. But shoals and bars cannot occur where the material of the bed is such as to offer a sufficient resistance to these actions, and when the stratum is perfectly hard and indurated; and as the tidal water and the pent-up river-water act as a scour during the ebb, the detritus, such as sand, gravel, silt, and mud, will be carried outwards to the sea, and the conflicting actions of the flood and ebb being stronger at the mouth of a river, have a greater tendency to throw up alluvial shoals and bars at that point. Now the velocity and mechanical power of a uniform stream of running water are increased by the augmentation of its depth; and the actual increments of the former vary as the square roots of the hydraulic mean depths, and of the sine of inclination conjointly, and of the latter as the quantity of water and the squares of the velocities. But in the case of tidal rivers, as, for instance, in the Thames, the increase of both the velocity and the power are only partial, as is plainly observable some time before and at the time of high-water. After overcoming the resistance of the river-water, the flow of the tide increases upwards for some time (probably about two-thirds of the time of its flow), from whence its velocity and power gradually diminish to the time of high-water.

There is a point of time too when the ebb tide has the greatest velocity, and this varies, in some degree, very probably, at every ebb. The ebb does not meet with retarding powers altogether similar to the flood. Immediately that the tide begins to recede, its velocity goes on increasing, and the mechanical action upon the channel also, until a certain time previous to low water, or when it loses that amount or body of water upon the channel, both in depth and power, which produces and constitutes the greatest velocity. In some degree, the precise time when the velocity is greatest will be dependent upon extraneous causes of retardation or acceleration. Thus the power of the wind acts, when ever it blows, either as an accelerating or retarding force, and, in consequence, may influence the precise or natural time of both the greatest velocities, and of low or high water. From observations, and by noting the full of the tide, it appears that the greatest velocity is at about one-third of the ebb; and under ordinary circumstances the flood runs up five hours, and the ebb runs down seven hours. The gradations of the velocity and power of the ebb go on increasing from high-water up to a certain point, and then diminish to nothing down to low-water. Diagrams shewing the increments and decrements of both the rise and fall of the flood and ebb tides at every quarter of an hour, and also the velocities due to the heights of each at the same time, and during the time of full and new moon, and from new to full moon, would be of great value to all persons engaged on, or in any way connected with the river. From knowing the times of high or low water one would, by inspecting the diagram, be enabled to see how much either the flood or ebb had increased or diminished at any point and time of the tides, and also the velocities at those points and times. These could be taken at various points in the river between Putney and Blackwall, and would serve as valuable indices to the state of the tides between those points; but such experiments should be placed under proper scientific supervision, and verified accordingly.

The bed of the river between London and Battersea bridges has been considerably deepened by dredging, and by the increased volume and action of the tides since the removal of old London-bridge; so much so as to have exposed the bases of the piers of Blackfriars and Westminster bridges; and, in consequence, placed their stability in considerable danger. At the low-water of the spring-tides the footings of the north piers of Waterloo and Southwark bridges are exposed, the dredging and action of the tides having ploughed much deeper channels between them than when they were first built. Since the removal of the great obstruction to the river, old London-bridge, the motive power of the ingress and egress of the tides has considerably increased beyond the tenacity and consistency of the soil and the stability of the channel; and there is no doubt that the contemplated embankment would produce a much greater change in the depth of its bed, so much so as that many of the bridges would require increased protection. The present greatest velocities of the ebb of the Thames between Westminster and London bridges increase as the breadth decreases. From the former of these points the breadth gradually diminishes to the latter, and consequently the velocities increase inversely as the areas of the sections. The following table will shew the greatest velocities of the ebb between those points:—

From Westminster to Waterloo bridges the greatest velocity at the surface is	=	40 in. per sec.
From Waterloo to Blackfriars, do. do.	=	50 ,,
,, Blackfriars to Southwark, do. do.	=	65 ,,
,, Southwark to London, do. do.	=	70 ,,

These are the velocities at the surface of the river in the run of the tide, but the water at the bottom, from the unevenness of the channel and other retarding causes, does not move with the same velocity as that on the surface. The latter is found thus: from the square root of the velocity at the surface in the middle of the stream, expressed in inches per second, subtract 1·03; the square of the remainder will be the velocity at the bottom; therefore, according to this rule,—

From Westminster to Waterloo bridges the velocity at the bottom is	=	24·031 in. per sec.
From Waterloo to Blackfriars, do. do.	=	35·295 ,,
,, Blackfriars to Southwark, do. do.	=	49·518 ,,
,, Southwark to London do. do.	=	53·923 ,,

It is of the utmost consequence attentively to consider and produce the stability and permanency of the channel. It is observable that by contracting the channel an augmentation of the velocity is imparted to the water, and this very materially increases the mechanical action of the stream; therefore it is essential, in order to obtain a stable and permanent channel, that the increased velocity and action correspond with the tenacity and consistency of the soil which form the bed of the river. According to the nature and ingredients of the soils which forms the bed of the stream, and the weight and size of the materials that lie upon the channel, from fine sand to large stones, a certain degree of proportional power is required to overcome the inertia of these bodies and to carry or drive them along. Therefore the substances will be acted upon by a momentum, more or less, according to the various velocities of the stream. An acquaintance with the velocity at the bottom of a running stream is most essential, in order to calculate what effect it may have upon the soil forming the bed of the river. In order to preserve an equilibrium between the action of the water and the tenacity and resistance of the channel, the nature and quality of the soil must be reciprocal to the momentum and abrasion of the water.

The motions of all running streams are excited and diminished in their rapidity by certain accelerating and retarding forces. The velocities which they begin to acquire in their descent would go on increasing as the square root of the perpendicular height of the declivity of the channel, and the depths of water due to their heads, were they not impeded by other retarding forces. That which makes all running streams uniform in their motions arises from the friction of the channels, and the tenacity, or the viscidity with which all the particles of the water are held together; and the velocities are owing to, and dependant upon, the declivities of their channels; the quantity of water discharged is also dependant upon the amount of the declivity; and, as was before observed, the quantity discharged is as the velocity; but the velocity is acquired from the inclination, for the surface of every fluid at rest is horizontal, and therefore cannot move until the surface is inclined to the horizon, when it immediately moves in obedience to the natural law of the force of gravity, as every particle of the stream endeavours to seek the lowest state of repose. Now the vertical section of a running stream varies as the inclination of the channel, for the declivity produces the velocity: thus, if a stream move along a channel with a mean velocity of 5 feet per second, and have a section 3 feet wide and 4 feet high, the discharge per second would be $3 \times 4 \times 5 = 60$ cubic feet, but if the same stream run further on in a similar channel, but with an increased declivity, which produces a mean velocity of 10 feet per second, the vertical section of the stream will be diminished to half the area of the former; for $3 \times 2 \times 10 = 60$ cubic feet as before. An increased velocity of a stream somewhat diminishes the pressure on the bed, and this also diminishes the friction and the resistance of the channel.

In order to preserve the channel of a river in a state of cleanliness, and to retain its uniformity, the scouring action of running water is the most efficacious mechanical agent; and this action becomes more powerful in preventing the deposition and accumulation of mud, and also of shoals of sand and gravel, when the quantity of running water is large, and moves with a high degree of velocity. A greater quantity of back-water is necessary in those rivers where the course is winding, for the purpose of keeping the channels free from deposits and accumulations, than in those whose courses are direct and straight; for in the former case a considerable quantity of the impetuosity and power of the moving current becomes destroyed by the reflected motions and eddies that are produced by striking against the sinuosities and projections of the banks, and from the centrifugal motions that are imparted to the stream in winding through the concave parts of the channel. Where the course of a river is of a serpentine form, it is observable that the mechanical action, from the greater velocity of the water along the concave portions of the banks, has deepened the channel much more at those parts than at the convex sides; and the abrading action of the currents upon the concavities is constantly wearing away those parts, the water carrying off the earthy particles of the soil, leaving the stony particles deposited upon the bed; because as the currents are reflected from the concavities on the one side into those on the other, the obliquity of the motions acts upon and wears away the bottom and banks, consequently, the convex banks are always less inclined to the channel, and much wider. But the declivity of the bed of a stream, whose channel is of a curvilineal form, is greater along a convex than along a concave bank, on account of the greater length of the curve at the latter part; for as the circumferences of curves increase

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